APPLICATION FOR UNITED STATES PATENT

Inventor(s):

1. Jae Sung Lim
   San 5, Ajou University, Woncheon-dong, Yeongtong-gu,
   Suwon-si, Kyeonggi-do 443-749, Republic of Korea
   (Citizen of the Republic of Korea)

2. Soon Jin Choi
   1595, Shinheong 2 –dong, Sujeong-gu, Seongnam-si, Kyeonggi-do
   461-162, Republic of Korea
   (Citizen of the Republic of Korea)

3. Eui Hyeok Kwon
   San 5, Ajou university, Woncheon-dong, Yeongtong-gu,
   Suwon-si, Kyeonggi-do 443-749, Republic of Korea
   (Citizen of the Republic of Korea)

Invention: METHOD AND APPARATUS FOR COMMUNICATING WITH SEVEN OR MORE TERMINALS EFFICIENTLY IN BLUETOOTH SYSTEM

LAW OFFICES OF ROYAL W. CRAIG
10 N. Calvert Street
Suite 153
Baltimore, MD 21202
Telephone: (410) 385-2382

METHOD AND APPARATUS FOR COMMUNICATING WITH SEVEN OR MORE TERMINALS EFFICIENTLY IN BLUETOOTH SYSTEM

CROSS-REFERENCE TO RELATED FOR APPLICATIONS

Pursuant to 35 U.S.C. 119(a) the present application derives priority from the following foreign filed patent application: Korean Patent Application No. 2003-22980 filed April 11, 2003.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to method and apparatus communicating with seven or more terminals efficiently in a Bluetooth system of a Wireless Personal Area Network (W-PAN), and more particularly, to communication method and apparatus in which a sniff mode allowing to be in a sleep state for a Sniff Interval Time (SIT) is converted into an active mode for a service such that a master can efficiently communicate with seven or more slaves using conventional seven Active Member Addresses (AM_ADDR).

2. Description of the Background

A Bluetooth system is a wireless communication technique in which short-range apparatuses such as a computer, a mobile phone, a headset, a printer, a PDA, a notebook, electric home appliances, etc. are connected using a wireless connection network to enable a duplex communication even without a complicated wire. The Bluetooth system is highlighted as a principal element for mobile communications, owing to its advantages such as a low-priced embodiment and a highly wide-range appliance. In recent years, service of the Bluetooth system is being provided centering the mobile phone, the headset, etc. using a Bluetooth protocol.

A communication between Bluetooth devices is performed based on a master-slave connection. The Bluetooth device, which establishes a frequency jump sequence to request the connection is called "master", and the Bluetooth device, which listens a connection request from the master and synchronizes to the frequency jump sequence of the master to accept the connection request is called "slave".

The Bluetooth devices in a standby mode detect approximate clock offset values and addresses of other devices through an inquiry and inquiry scan process. And thus, through a paging and paging scan process, a nodes connection can be constructed. FIG. 1 is a view illustrating a piconet consisting of one master and several slaves in a conventional Bluetooth system. As shown in FIG. 1, one master can include seven slaves being in an active mode.

A connection between one master and one or more slaves is called "piconet", and each of the slaves is distinguished using a 3-bit active member address.

Accordingly, in one piconet, only seven slaves can perform a communication, and more than seven slaves are allocated and given parameters to be used in a parking mode such as a Park Member Address (PM_ADDR), an Access Request Address (AR_ADDR), etc. from the master, and then enter the parking mode to be in the sleep state. This procedure is called "parking".

Further, when the parked slaves again request to communicate with the master, they use the access request address to transmit the access request message to the master through a beacon channel. The master receives the access request message to check a communication resource of itself and then to accept a call. This procedure is called "un-parking".

On the other hand, the Bluetooth piconet follows a Time Division Duplex (TDD) way controlled by the master. Therefore, for allocation of a time slot to the slave, the master transmits a data packet or a control packet to the slave such that the slave can be allocated and given the time slot so as to transmit the packet to the master.

What the master transmit a packet to the slave in order to allocate a time slot to the slave is called "polling". In case there exists data to be transmitted, the data packet is transmitted, and in case not existing, a null packet is transmitted.

As described above, the conventional Bluetooth system cannot, in one piconet, provide a service for more than seven slaves. In one Bluetooth piconet, more than seven Bluetooth devices are served in conventional two methods.

In a first method, the active mode of the slave being now in service is converted into the parking mode, and then a returned active member address is allocated to a new slave so as to provide the service. But, such method has a drawback in which one or more slaves among slaves being now in service are forcibly interrupted thereby resulting in deteriorating a quality of the service. Further, the conventional method has another drawback in which since it takes a long delay time for the parking or the un-parking, a service delay is lengthen and an efficiency of a throughput is decreased.

In another method, a Scatternet is used. A connection between more than two piconets is called "Scatternet", and this conventional method has a drawback in which because of various reasons such as the fact that in a present standard, a detailed protocol is not yet defined, the service is impossible.

SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to method and apparatus for communicating with seven or more terminals in a Bluetooth system that substantially obviate one or more problems due to limitations and disadvantages of the related art.

An object of the present invention is to provide method and apparatus for communicating with seven or more terminals in a Bluetooth system, in which a multiple access scheme is

provided for enabling a master to efficiently communicate with seven or more slaves thereby improving a system performance and being used in various appliances.

Additional advantages, objects, and features of the invention will be set forth in part in the description which follows and in part will become apparent to those having ordinary skill in the art upon examination of the following or may be learned from practice of the invention. The objectives and other advantages of the invention may be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

To achieve these objects and other advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, there is provided a method for communicating with seven or more terminals in a Bluetooth system having a master and a plurality of slaves, the method including the steps of: checking an active member address to be allocated to a new slave such that the master establishes a communication connection with the slave; in case the active member address remains, allocating the remaining active member address to the slave, and in case the active member address does not remain, calculating a service delay time to compare the calculated delay time with a predetermined reference value; in case the service delay time is larger than the predetermined reference value, permitting a call acceptance, and in case the service delay time is smaller than the predetermined reference value, determining a service sequence with respect to a predetermined reference according to the number of the slave calculated at a pre-scheduling duration; allocating a sniff interval time and the active member address to each of the slaves according to the service sequence, and converting the slave allocated and given the sniff interval time and the active member address to be in a sniff mode; and waking-up the slave of the sniff mode at the sniff interval time such that

the active member address is used to complete the communication with the master and return the active member address.

In another aspect of the present invention, there is provided a communication method with seven or more terminals in a Bluetooth system having a master and a plurality of slaves, the method including the steps of: transmitting an access request message from a parked slave to the master so as to establish a communication connection therebetween; receiving the access request message so as to calculate the number of the parked slave and determine a service sequence with respect to a predetermined reference; allocating an active member address according to the service sequence so as to establish the communication connection, and maintaining a non-connection slave to be in a sleep state in a sniff mode; and waking-up the slave of the sniff mode at the sniff interval time such that the active member address is used to complete data transmission with the master and return to a parking mode.

In a further aspect of the present invention, there is provided an apparatus for communicating with seven or more terminals in a Bluetooth system having a master and a plurality of slaves, the apparatus including: a transceiver for transmitting and receiving a signal between the master and the slave; a parking mode controller for analyzing the signal received from the transceiver so as to control the number of a parked slave, a data type and the number of packet, and a parameter necessary for a parking mode; a pre-scheduling unit for analyzing the signal received from the transceiver so as to determine a service sequence, a sniff interval time and an active member address; and a controller for controlling the parking mode controller, the transceiver and the pre-scheduling unit such that the slave is activated according to the service sequence so as to perform the communication.

It is to be understood that both the foregoing general description and the following detailed description of the present invention are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide a further understanding of the present invention and are incorporated in and constitute a part of this application, illustrate embodiment(s) of the present invention and, together with the description, serve to explain the principle of the present invention. In the drawings:

FIG. 1 is a view illustrating a piconet consisting of one master and several slaves in a conventional Bluetooth system;

FIG. 2 is a view illustrating a piconet in which a master efficiently communicates with seven or more slaves according to a preferred embodiment of the present invention;

FIG. 3 is a flowchart illustrating an operation procedure of a Bluetooth system in a piconet according to a preferred embodiment of the present invention;

FIG. 4 is a timing diagram illustrating an operation procedure according to a preferred embodiment of the present invention;

FIG. 5 is a flowchart illustrating an operation procedure in a Bluetooth system performing the communication with seven or more slaves using a parking mode according to a preferred embodiment of the present invention;

FIG. 6 is a timing diagram depicting an establishment of a Bluetooth channel according to a preferred embodiment of the present invention;

FIG. 7 is a detailed timing diagram illustrating a timing diagram of FIG. 6;

FIG. 8 is a block diagram illustrating a communication apparatus according to a preferred embodiment of the present invention;

FIG. 9 is a graph depicting a delay time depending on the increasing number of a node as an experimental result according to a preferred embodiment of the present invention;

FIG. 10 is a graph depicting a throughput depending on the increasing number of a node as an experimental result according to a preferred embodiment of the present invention; and

FIG. 11 is a graph depicting a channel utilization depending on the increasing number of a node as an experimental result according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

FIG. 2 is a view illustrating a piconet in which a master efficiently communicates with seven or more slaves according to a preferred embodiment of the present invention. Referring to FIG. 2, a Bluetooth system includes a master for managing all communications in the piconet, and a plurality of slaves for communicating with the master. Further, the plurality of slaves can be operated in various modes such as a hold mode, a sniff mode and a parking mode. The slave now having a communication connection with the master is called "active slave", and the slave not having the communication connection with but synchronizing to the master is called "parked slave". The master distinguishes each of the active slaves using 3-bit active member addresses (AM-ADDR) (001~111).

FIG. 3 is a flowchart illustrating an operation procedure of the Bluetooth system in the piconet according to a preferred embodiment of the present invention, and FIG. 4 is a timing

diagram illustrating an operation procedure when the number of slaves is equal to 8 in the piconet (N = 8).

First, in order to commence the communication, the master respectively allocates the active member addresses (001 - 111) to the slaves such that the slaves are distinguished from one another to perform the communication (S100). Accordingly, in a case where the master establishes a call connection with a new slave, it checks a presently remaining active member address (S110). In a case where there exists an active member address to be allocated, the master allocates the existing active member address to the slave requesting the communication (S120). However, in a case where more than seven slaves are already allocated and given all the active member addresses and resultantly there no longer exists an active member address to be allocated, a traffic load of the master being now in service is measured so as to determine whether the master can additionally accept the slave (S130). Herein, the traffic load represents a delay time taken to store and serve a packet in a queue of the master, and it is desirable that a calculation result is expressed in a slot unit.

Equation 1:

$$D_{SERVICE} = \frac{\sum_{slave=1}^{U} N_{slave}}{\mu} < D_{TH}$$

Herein, "N_{slave}" represents an average of the number of the packet stored in a queue of each slave for a predetermined time, and "μ"represents an average of the number of the packet transmitted from the master. Accordingly, if a value of the delay time ($D_{SERVICE}$) taken for the

master to process is larger than a reference value (D_{TH}), the master determines that it no longer can accept the slave to reject a call acceptance (S140). If the value ($D_{SERVICE}$) is smaller than the reference value (D_{TH}), the master accepts the call acceptance so as to convert a call requesting slave to be in the sniff mode such that until present services of the active slaves are finished, the call requesting slave is in the sleep state for a data transmission duration (T_{D_T}).

In FIG. 4 illustrating a timing diagram for an operation procedure according to a preferred embodiment of the present invention, there is illustrated a state of the call acceptance for eight slaves as an embodiment. At this time, according to the number of slaves calculated for a pre-scheduling duration (T_{P_S}), the master determines a sequence of services (S150), and thus allocates, to the slave that intends to enter the sniff mode, a Sniff Interval Time (SIT) represented by the number of the slot and the Active Member Addresses (AM_ADDR) (001~111) that is used for the slave to communicate with the master after being woken-up at the sniff interval time (SIT) (S160).

The following equation 2 is an example for obtaining the sniff interval time.

Equation 2:

$$SIT = N * F + N_{th}$$

Herein, "N" is the number of slave intending to communicate with the master at present, "F" is a frame unit as a service sequence of the frame, and "N_{th}" is a slave position in one frame. For example, the sniff interval time of an eighth slave in a first frame is calculated as follows:

SIT = 8 * 1 + 8 = 16.

Data transmission of the slave is repetitively performed during the data transmission duration in the frame unit. That is, each of the slaves uses a polling way using a poll packet, but

the data transmission is performed using a Time Division Multiple Access (TDMA) way of transmitting data according to a predetermined sequence.

The master manages a slave identification (ID) and the active member address used in the slave, while it communicates with a number of slaves.

Table 1 is an example of a mapping table of the master, and Table 2 is an example of a mapping table of the slave.

Table 1:

Slave ID	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AM_ADDR	001	010	011	100	101	110	111	001	010	011	100	101	110	111	001	010
SIT	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Table 2:

AM_ADDR	001	010	011	100	...	010
SIT	16	24	32	40	...	998

In the above cases, the active member address 001 is jointly allocated to the slave 1, slave 8 and slave 7. Accordingly, the slave 1 is first under data service, and the remaining slave 8 and slave 7 enter the sleep state through the sniff mode (S170). At this time, after the slave 8 and the slave 7 are woken up after the sniff interval times (SIT) different from each other, they use the

active member address (001) so as to communicate with the master. That is, the slave 8 and slave 7 are woken up after the sniff interval time (SIT) following the time when the service of the slave 1 is finished such that they can receive the poll packet of the master so as to communicate with the master (S180). Next, the slave 7 checks whether data to be communicated remains and as a result, in a case where it is determined that all data are communicated, the active member address is returned to the master (S190)(S200).

The communication method according to another embodiment of the present invention will be described hereinafter.

One master manages the piconet consisting of a number of slaves. If the slaves do not perform the data communication with the master, in order to prevent a consumption power from being wasted, the parking mode is maintained. The parked slaves are distinguished from one another using an 8-bit Park Member Address (PM_ADDR), and they can use the 8-bit Access Request Address (AR_ADDR) so as to transmit the access request message to the master.

FIG. 5 is a flowchart illustrating an operation procedure in the Bluetooth system performing the communication with seven or more slaves using the parking mode according to a preferred embodiment of the present invention.

FIG. 6 is a timing diagram depicting an establishment of a Bluetooth channel according to a preferred embodiment of the present invention, and FIG. 7 is a detailed timing diagram depicting the timing diagram of FIG. 6.

Referring to FIGs. 5 to 7 in combination, while in a communication disconnection state with the master, the parked slaves maintain only synchronization with a period of a beacon interval duration (T_{B_I}), in a case where there is data to be transmitted to or received from the master, in order to establish the communication connection with the master, the parked slaves transmit the access request message to the master at an access window duration (T_{a_W}) of a

beacon channel duration (T_{B_C}) (S300). In FIG. 7, the beacon train duration (T_{B_T}) is a duration for which a beacon instant is repetitively transmitted. In order to increase reception rates of the slaves in the parking mode, it is desirable that the beacon instant is repetitively transmitted. Further, a slot (T_W) of the access window duration is a slot allocated to one parked slave, and for this slot duration (T_W), the access request message is transmitted. Additionally, T_{NEW} is a duration for which a new connection slave with the master is detected, and for this duration, an inquiry scan and paging scan procedure is performed.

In one embodiment of the present invention, the polling scheme is used to broadcast the beacon packet to all the parked slaves, and each of the slaves transmits the access request message for the access window duration (T_{a_w}). In particular, in one embodiment the access window duration (T_{a_w}) can be allocated to one slot, and in another embodiment, it is possible to allocate a plurality of slots considering a re-transmission scheme so as to increase an accessing probability of the slave.

Further, in other embodiments, it is also desirable that the master employs a slotted Collision Sense Multiple Access (CSMA) way or a Time Division Multiple Access (TDMA) way so as to provide a connection chance to all the parked slaves. The master receives all the access request messages that the parked slaves transmit in the pre-scheduling duration (T_{P_S}) so as to calculate the number of the parked slave intending to communicate with the master at present (S310).

Further, according to the calculated number of the slave, the service sequence is determined with respect to a predetermined reference. And, the service sequence can be determined in a sequence of receiving the access request message in the master. And, depending on any case, the service sequence can be determined prioritizing the slave not having data

transmission for the beacon interval duration (T_{B_I}) earlier, so as to provide the fairness of the system.

First of all, seven slaves having the service allocated are served using seven active member addresses, and more than seven slaves are maintained in the sniff mode to be in the sleep state for a low power consumption, while they are in standby until served. Before the slaves enter the sniff mode, the slaves are, in the pre-scheduling duration (T_{P_S}), allocated and given the sniff interval time (SIT) representing a waking-up time of the slaves from the sniff mode to the active mode and a parameter of the active member address (AM_ADDR) to be used after woken up (S320). In other words, according to the determined sequence, the master provides the service for all the slaves having data, using seven active member addresses (S330).

Next, the slaves in the sniff mode are woken up from the sleep state after the sniff interval time (SIT), and then just after the slaves receive a polling from the master, they operate as the active slaves (S350).

This operation is repeated until the services of all the slaves earlier transmitting the access request message at the beacon channel duration (T_{B_C}) are finished (S360).

Further, during the data transmission duration (T_{D_T}), the slave performs the communication with the master one time, if the slave additionally has data to be transmitted, the slave can be continuously served until the beacon interval duration (T_{B_I}) finishes. If the slave does not finish the communication with the master at the data transmission duration (T_{D_T}), the slave is again, at next data transmission duration (T_{D_T}), maintained to be in the standby in the last position of the slaves in the sniff mode for the future data transmission (S370).

In various ways, the frame being scheduled at the data transmission duration (T_{D_T}) can be transmitted. In one embodiment, after all of the slaves transmitting the access request message at the beacon channel duration (T_{B_C}) are un-parked, the un-parked slaves are

established in the frame, and after all of the slaves transmit data by one time, they enter the parking mode. This way is appropriate for appliance service in which a number of nodes such as a wire sensor network transmit small data very intermittently.

In another embodiment, all the un-parked slaves are bundled with the frame, and a service authority in the frame unit is given for the slaves. That is, during the data transmission duration (T_{D_T}), data is sequentially transmitted in the frame unit, and when the data transmission duration (T_{D_T}) finishes, all the slaves are automatically parked. Together with this, in a case where the slave, having the active member address (AM_ADDR) once allocated, after the next sniff interval time (SIT), still also has data to be transmitted, it is also possible to be again established for the data transmission. The slave completely finishing the data communication returns the active member address to the master, and returns to enter the parking mode (S380).

A communication apparatus for embodying the communication method of the above-described Bluetooth system will be described.

FIG. 8 is a block diagram illustrating the communication apparatus according to a preferred embodiment of the present invention. Referring to the FIG. 8, the communication apparatus includes a transceiver 30, a pre-scheduling unit 40, a parking mode controller 20 and a controller 10.

The transceiver 30 processes a transmittance/reception signal between the master and the slave.

Further, the pre-scheduling unit 40 analyzes the signal received from the transceiver 30 so as to determine a sequence of the slaves to be served, and at this time, in order to convert the slaves to be in the sleep mode, it determines the sniff interval time (SIT) representing, in a slot unit, the time for which the sniff mode is maintained, and the active member address (AM_ADDR) to be used after waking-up. Additionally, considering the fairness of the service,

it is desirable that the service sequence is determined prioritizing the slaves not having data transmission during the beacon interval duration (T_{B_I}) earlier. The pre-scheduling unit 40 can allow a kind of the packet to be automatically varied according to a communication throughput provided by the slave. This causes the throughput of the system to be increased and an unnecessary control packet to be prevented. For example, in case the slave has large data, a data high rate 5 (DH5) or DH 3 packet is used. In case the slave has small data, the sniff interval time (SIT) of the case using DH 1 packet or Data medium 1 (DM1) packet is calculated. This is because according to the kind of each packet, the number of the slot occupied is determined.

The parking mode controller 20 uses the reception signal from the transceiver 30 so as to calculate the number of the parked slave, an information type and the number of the packet that each of the slaves intends to transmit, and parameters necessary for the parking mode. The parameters include each kind of parameters used when the service using the parking mode is provided, for example, the number of the beacon slot, the number of the access window, the number of the slot per the access window, etc.

Lastly, the controller 10 controls the parking mode controller 20, the transceiver 30 and the pre-scheduling unit 40 such that, according to an established sequence of the pre-scheduling unit 40, the slave entering the sniff mode can become the active slave so as to perform the communication.

The following are graphs comparing the results according to the conventional Bluetooth system and the embodiment of the present invention so as to evaluate a performance of the present invention.

Calculation parameters for evaluating the performance of the present invention are expressed as the service delay time (Delay), the throughput, and the channel utilization.

FIGs. 9, 10 and 11 are respectively the graphs illustrating the delay time, the throughput and the channel utilization depending on the increasing number of the node as experimental results according to a preferred embodiment of the present invention. In order to evaluate respective performances, a computer simulation is used, and each of the traffic generations is modeled. In other words, it is assumed that a fixed size of data is generated at respective nodes according to a Poisson distribution. In order to compare the performance of the conventional Bluetooth system and the present invention, the beacon interval duration (T_{B_I}) is 1.28 seconds and an average traffic generation interval time is 2 seconds, and the number of the node are increased by 250.

As shown in FIG. 9, the delay time represents an average time taken to transmit one packet. In the conventional Bluetooth system, as the number of the node is increased, the service delay time is rapidly increased, while in the present invention, the service delay time is not almost varied.

FIG. 10 is a graph quantitatively illustrating the data throughput, and illustrates a ratio of transmission packet to the packet generated in one node. For example, a numeral 1 means that the packets generated from one node are all transmitted. As shown in the graph of FIG. 10, as the number of the node increases, the throughput is decreased in the conventional Bluetooth system, whereas in the present invention, all the packets are processed without deteriorating the performance.

As shown in FIG. 11, the graph illustrates that the channel utilization of the present invention is excellently high. This is because in the conventional Bluetooth system, though the data transmission duration (T_{D_T}) is enough, since only seven slaves are received, until the next beacon channel duration (T_{B_C}), a void slot is more generated.

As appreciated from the above-described embodiments, in the Bluetooth system according to the present invention, the master simultaneously provides the service for seven or more slaves to thereby provide an excellent performance of the data transmission delay, the throughput and the channel utilization in a whole system.

Further, the present invention solves a disadvantage of seven active slaves included in the Bluetooth system to thereby be capable of applying in various appliances. For example, in a wireless sensor network managing a number of nodes of processing small data, datum on a number of nodes can be efficiently accepted, and in a service hot spot such as an airport, even various web information users can be simultaneously served through the Bluetooth system.

It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention. Thus, it is intended that the present invention covers the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.